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VELA NETWORK EVALUATION AND AUTOMATIC PROCESSING RESEARCH

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QUARTERLY REPORT NO. 5
1 OCTOBER 1977 TO 31 DECEMBER 1977

TEXAS INSTRUMENTS INCORPORATED
Equipment Group
Post Office Box 6015
Dallas, Texas 75222

Contract Number: F08606-77-C-0004
Amount of Contract: $1,034,000
Beginning 1 October 1976
Ending 30 September 1978

Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER
Alexandria, Virginia 22314

Sponsored by

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Nuclear Monitoring Research Office
ARPA Program Code No. 7F10
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This fifth quarterly report summarizes progress under the VELA Network and Automatic Processing Research program, Contract Number F08606-77-C-0004, during the period 1 October 1977 to 31 December 1977 and summarizes work performed during the period 1 October 1976 to 30 November 1977 under VT/7705. Work in the following areas is summarized:

- (1) SRO Evaluation;

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- (2) Detection, Waveform Extraction, and Magnitude Estimation;
- (3) Event Identification Study;
- (4) Surface Wave Study; and
- (5) Seismic Data Management.

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SECTION I
INTRODUCTION AND SUMMARY

This fifth quarterly report summarizes the work performed during the period 1 October 1976 to 30 November 1977 under AFTAC Project Number VT/7705. Also presented is a summary of the progress made during the period 1 October 1977 to 31 December 1977 under AFTAC Project Number VT/7805 in the VELA Network Evaluation and Automatic Processing Research program currently being conducted by Texas Instruments Incorporated at the Seismic Data Analysis Center (SDAC) in Alexandria, Virginia.

The tasks studied under Contract Number F08606-77-C-0004 included the following:

- Evaluate available data from the Iranian Long Period Array (ILPA), and the Seismic Research Observatories (SRO) in terms of regionalized detection and discrimination capability.
- Investigate the following points - the performance of an automatic signal detector which uses the power in multiple frequency bands; methods aimed at improving the automatic timing of signal arrivals for short- and long-period signals; the signal-to-noise improvement gained by using high convergent rate adaptive beamforming; design and performance guidelines of detection association algorithms; and bias in network magnitude estimates.
- Develop and apply processing techniques to extract useable long-period bodywaves. Determine the improvement in signal extraction capability that is obtained when previously developed

signal enhancement techniques are applied sequentially to a signal.

- Using the interactive graphics processing system for the PDP-15 computer, develop the software necessary to support an off-line, operationally interactive system which could be used for standard seismic processing functions. Develop the necessary software to input and retrieve KSRS data from the mass storage facility.
- Using data from the long-period network, determine seismic source parameters for selected events from the Nevada Test Site, foreign explosions, and Eurasian PNEs.

Twelve technical reports were prepared to describe the results of the work performed on these tasks. These reports are summarized in Section II.

The five program tasks currently being worked on under AFTAC Project VT/7805 are:

- Evaluate the performance of the Seismic Research Observatories (SRO)
- Develop advanced methods for detecting seismic events, extracting waveforms, and measuring magnitudes
- Develop and test an event identification package which performs multivariate discriminant analysis of a data base of seismic events, classifying them as earthquakes or explosions
- Perform a surface wave study to determine source mechanisms of explosions and earthquakes; correcting for propagation effects

- Develop seismic data management software for retrieval from the seismic data Mass Store and for internal transfers to the PDP-15 for routine processing.

The Research Objective Plan for performing these tasks is now under preparation. During this quarter we completed the planning, some of the data preparation, and some of the development for the above tasks.

For the SRO data evaluations, work was concentrated in the following areas:

- Establish and maintain contact with the Albuquerque Seismological Center for cooperation in evaluating SRO data
- Expand the data base using the National Earthquake Information Service (NEIS) lists available
- Maintain data preparation software which are primarily edit and plotting programs
- Prepare software for extended noise analysis
- Perform the routine signal processing and analysis needed to evaluate each station separately and to evaluate all stations as a network designed to locate and measure earthquakes and presumed explosions.

To develop advanced methods for detecting, extracting, and measuring seismic events, three research tasks are being pursued. These are as follows:

- Perfect and test methods for improved detection, automatically timing the arrival of seismic events, and extracting event waveforms
- Determine advanced methods of using an adaptive beamformer to detect weak signals generated by seismic events

- Test methods for reducing the bias of magnitude measurements of seismic events.

To develop routine event identification techniques, four tasks are being performed as follows:

- Survey literature to obtain a comprehensive list of identification criteria
- Develop routine methodology for computing discriminant measurements as part of our data preparation procedure
- Develop methodology for reducing discriminant measurements to a set of multivariate event statistics
- Develop methodology for optimum event identification classification of events as explosions from a region or as earthquakes.

To evaluate surface wave source mechanisms four tasks are being performed:

- Use newly developed and existing software for spectral analysis corrected for instrument response, path attenuation, and dispersion
- Form a suitable data base with long-period waveforms measured at a large number of stations providing adequate azimuthal coverage of the event
- Compare these to theoretical spectra and radiation patterns derived from the best fit source model as a means of estimating the source parameters associated with an event
- Compare parameters derived from presumed explosions to those derived from earthquakes.

To develop seismic data management software two tasks are being performed:

- Develop software necessary to retrieve KSRS data from the Mass Store, to be executed on the PDP-11 as a Mass Store Data Retrieval System (MSDRS), and to be interfaced with Lincoln Laboratories data language software
- Establish procedures and software to transfer data retrieved by MSDRS to the PDP-15 for routine processing.

SECTION II
SUMMARY OF REPORTS

The results of the work performed during 1 October 1976 to 30 November 1977 on the tasks described in Section I are reported in a series of twelve technical reports. This section will briefly summarize these reports.

A. EVALUATION TASKS

The purpose of these tasks was to determine on a regionalized basis the detection and discrimination capabilities of the Iranian Long Period Array (ILPA) and the Seismic Research Observatories (SRO). The ILPA evaluation was described in Technical Report No. 1 and the SRO evaluation in Technical Report No. 2. Improvements in the software used in these evaluations are described in Technical Report No. 10.

1. Technical Report No. 1: Continuation of the Iranian Long Period Array Evaluation

This report presented a continuation of the evaluation of the Iranian Long Period Array (ILPA).

In the area of long-period noise analysis, this report discussed RMS noise levels and trends and average noise RMS amplitude spectra for both the individual sites and the beamformed data. The array noise data was also used to investigate the questions of noise coherence and propagating noise.

In the area of signal analysis, signal-to-noise ratio gains due to beamforming and site-to-site signal similarities were investigated. Using a processed data base of 613 events, regionalized detection capability estimates and earthquake-presumed explosion discrimination were investigated. Finally, the report presented a comparison of the array and the closest Seismic Research Observatory station.

The major conclusions of this report are:

- In general, the data quality is fairly good. Of 680 events examined, 6.6% were lost due to unreadable data, 6.2% were lost due to gaps in the recorded data, and 4.1% were lost due to uncorrectable system malfunctions.

- Noise suppression due to beamforming is greater on the vertical component than on either of the horizontal components.

- The level of multichannel coherence in the 0.023-0.059 Hz filter passband is high enough that multichannel filtering may be effective.

- There is very little 0.01172 Hz propagating noise arriving at ILPA.

- The majority of 0.04297 Hz and 0.05859 Hz propagating noise with signal phase velocities have arrival azimuths directed toward the south, away from the general seismic area of interest.

- The highest gain in signal-to-noise ratio due to beamforming was 6.9 dB on the vertical component. Gains on the transverse and radial components were 4.4 and 4.0 dB, respectively.

- The absolute 50 percent detection capability estimate for ILPA beam data using NORSAR m_b values is at $m_b = 4.42$ for Eurasian events. The absolute detection capability estimate was computed by including all mixed events, events for which no data were available and events containing malfunctions as non-detections.

- The conditional 50 percent detection capability estimate for ILPA beam data using NORSAR m_b values is at $m_b = 3.94$ for Eurasian events. The conditional detection capability estimate was computed by excluding all mixed events, events for which no data were available and events containing malfunctions from the detection statistics.

- Using the $M_s - m_b$ discriminant and a set of five suspected nuclear explosions, two of the five were classified as earthquakes and two as nuclear explosions. One of the five could not be classified as either earthquake or explosion.

- Due to the beamforming process, the probability of an event being mixed decreases with increasing bodywave magnitude at ILPA while remaining fairly constant at MAIO.

- While the RMS noise levels at ILPA are slightly greater than those at MAIO, beamforming produces an average noise suppression of 4.0 dB at ILPA relative to MAIO.

- The conditional detection capability estimate as defined above at ILPA is approximately 0.2 m_b units lower than that of MAIO.

2. Technical Report No. 2: Continuation of the Seismic Research Observatories Evaluation

This report presented the results of a continued evaluation of the Seismic Research Observatory stations. During the time period this evaluation was carried out, data were available from six stations - Albuquerque, New Mexico (ANMO); Guam, Marianas Islands (GUMO); Mashhad, Iran (MAIO); Narrogin, Western Australia (NWAO); Taipei, Taiwan (TATO); and Wellington (South Karori), New Zealand (SNZO).

In the area of noise analysis, this report discussed RMS noise levels and RMS noise trends for short-period and long-period data and noise spectral content for long-period data. Daily noise samples for approximately a nine-month period were used in this investigation.

Individual station detection and discrimination capability estimates on a regionalized basis were determined for each station using a large data base. Depending on the station, this data base ranged from 600 to 1200 events. SRO network detection capability was also estimated.

In the course of processing and analyzing data for these areas of investigation, estimates were made of the data quality, station reliability, and probability of mixed events.

The major conclusions reached in this report are:

- Estimates of station reliability were based on the frequency of occurrence of malfunctions and on estimates of station down-time. GUMO had the lowest reliability (0.7) due to a relatively large amount of station down-time. The other stations had reliability factors of 0.8 or above.

- The probability of an event being mixed was estimated at approximately 0.3, with little variation from station-to-station, in a range of m_b values from 3.1 to 5.0.

- Estimates of short-period RMS noise values in the 0.5-4.0 Hz passband (uncorrected for instrument response) are: 0.38 mμ at ANMO, 0.57 mμ at MAIO, 7.69 mμ at NWAO, 20.61 mμ at TATO, 28.92 mμ at SNZO, and 40.25 mμ at GUMO. These show strong correlation with station-coastline separation.

- Based on long-period RMS noise levels in the 0.023-0.059 Hz passband, the stations can be divided into two groups - ANMO and MAIO form the group with lower RMS noise levels and GUMO, NWAO, and TATO form the group with higher RMS noise levels. Considering the locations of these stations, this suggests that there is only a weak correlation between station-coastline separation and long-period noise level.

- No short-period events of the data base were detected at SNZO, while only two were detected at GUMO.
- Mixed events had very little effect on short-period detection capability.
- Station down-time reduced ANMO short-period detection capability by 0.2 m_b units.
- Malfunctions reduced MAIO short-period detection capability by approximately 0.1 m_b units.
- Mixed events decreased NWAO long-period detection capability by 0.3 m_b units.
- Mixed events, system failures, and malfunctions equally decreased the SNZO long-period detection capability by 0.3 m_b units.
- Mixed events, and to a lesser degree system failures and malfunctions decreased ANMO, MAIO and TATO long-period detection capability 0.4 m_b units.
- System failures, and to a lesser degree mixed events, decreased GUMO long-period detection capability by 0.5 m_b units.
- Surface wave magnitudes of presumed nuclear explosions from the Nevada Test Site fell into the earthquake population on M_s - m_b discriminant plots.
- Surface wave magnitudes of two out of six presumed Eurasian nuclear explosions fell into the earthquake population on M_s-m_b discriminant plots.

- Short-period detection capability is poorer than long-period detection capability for all regions. This may be temporarily due to the effect of the automatic detector on the short-period data.

3. Technical Report No. 10: Seismic Data Preparation Procedures

The computer programs currently being used to prepare seismic data for analysis on the PDP-15 computer, and the flow of data through them, are described briefly. The programs are being run by Texas Instruments Incorporated on the IBM 360/44 at the Seismic Data Analysis Center. New programs developed during the contract period are described in some detail. Some suggestions for future work are provided.

This report concerns development of computer programs on the IBM 360/44 computer at the Seismic Data Analysis Center (SDAC). The programs prepare seismic data for analysis on the PDP-15 computer by extracting selected events, removing the mean from each trace, and, if desired, rotating the data and beamforming them. The input data for these programs come, in part, from magnetic tapes sent in from the field. The goal is to put the data onto tapes in event/station/component form, suitable for input into the Interactive Seismic Processing System (ISPS) on the PDP-15 (Ringdal, et al., 1975).

Documentation is provided in this report for the recently developed array and single-site data processing programs. Three separate programs were used to edit ALPA, LASA, and NORSAR data recorded before 1975. These three have been combined into one program TITRIEDT for data recorded after 1975. The programs used to edit, rotate, filter, and plot SRO data were combined into one program called TISROPRG. One SRO short-period edit program called TISROSPE was also developed.

B. SEISMIC DETECTION METHODS

1. Technical Report No. 3: The Deflection Detector - Its Theory and Evaluation on Short-Period Seismic Data

This report described the application of a deflection detector to short-period seismic data. In general, for power detectors, no single filter will be optimal for a large class of signals in a dynamic noise environment. The deflection detector represents an attempt to adapt to such a situation by utilizing individual FFT frequency cells as a bank of filters which can accommodate a broad class of signals.

The deflection detector and the conventional power detector were compared and evaluated on a set of four seismic events buried in seismic noise. The detection performance of the deflection processor was the same for one of the signals, showed a 2 dB relative loss in signal-to-noise ratio processing ability for a second signal, and a 2 dB gain for the two remaining signals. More generally, it was found that the deflection algorithm is at an advantage in detecting signals of enhanced high frequency energy content above 1.25 Hz. Such signals appear to have narrowband signal-to-noise spectra with seismic noise power concentrated at the lower frequencies. This results in greater coherent gain.

The potential usefulness of the deflection detector is perhaps better visualized in a more general setting. Figure II-1 illustrates three levels of signal information and appropriate detector configurations. Although the deflection detector and power detector are placed on the same level, the deflection detector possesses more versatility when the class of signal spectra is large. For a single known signal, the ideal detector is a matched filter. However, for the detection of a whole class of signals of diverse spectral content, the matched filter or shaped filter should be replaced by a bank of filters (one for each signal type) and a rule for deciding between signals. The deflection processor actually does this in a rudimentary manner with FFT

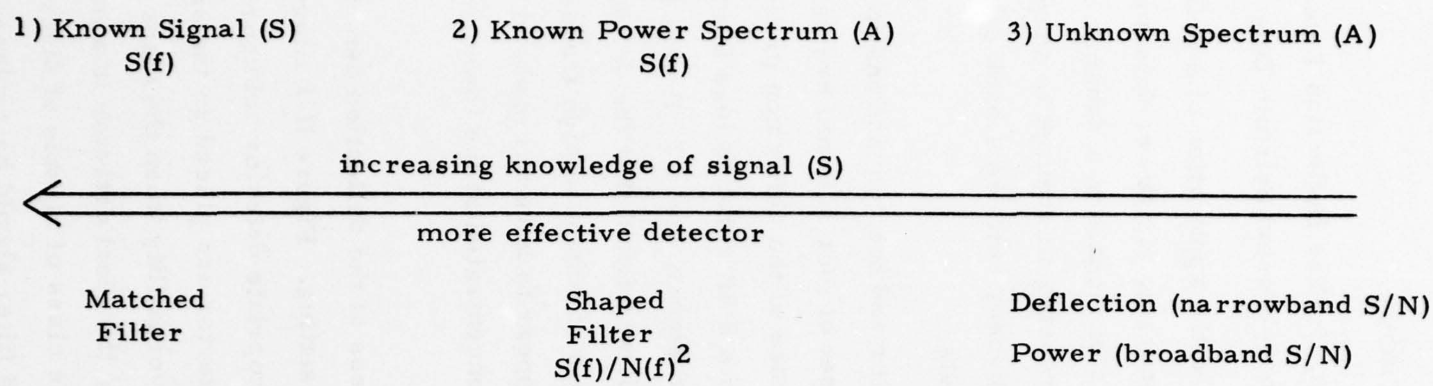

FIGURE II-1

RELATIONSHIPS BETWEEN A PRIORI KNOWLEDGE OF SIGNAL AND DETECTOR DESIGN cells used as bandpass filters. Clearly, a crucial design factor is the determination of the number of signal types in the class to be detected and the modeling of those signals. Thus, an evaluation of the usefulness of the deflection processor and for the construction of a more powerful detector require a thorough study of the signal spectra and noise spectra in the region of interest.

2. Technical Report No. 4: Automatic Detection, Timing and Preliminary Discrimination of Seismic Signals with the Instantaneous Amplitude, Phase, and Frequency

The feasibility is evaluated of applying instantaneous amplitude, phase and frequency measurements to automatically detect, time, and identify seismic events. Detection based on phase measurements is shown to be in principle 6 dB more sensitive than detection based on amplitude measurements. A phase detection and timing algorithm, using a priori known dispersion characteristics, is demonstrated to time the onset of teleseismic long-period surface waves within 40 seconds accuracy in 75% of the cases, for waveforms of 0 to 4 dB signal-to-noise ratio. By phase measurement, rather than by amplitude measurement, this algorithm also provides a measure of the surface wave signal-to-noise ratio. These results can be applied in the extraction of weak surface waves.

Phase detection of teleseismic short-period bodywaves was not found to be feasible due to the interference of early-arriving secondary signals. Therefore, short-period P-wave detection and timing are performed essentially by envelope peak detection; instantaneous frequency measurements are also used in the timing process. Tested on a small data base, this method resulted in 81% to 94% detection at 7 to 20 false alarms per hour, with signal-to-noise ratio thresholds of 2 to 3 dB. The RMS timing error, relative to analyst picks, was 0.23 seconds, comprising 77% of the test cases; this timing error apparently was independent of the signal-to-noise ratio. In some cases, however, noise can obscure the true signal onset for the analyst as well as for the automatic timing algorithm. It is shown that this can cause as much as 0.4 seconds absolute timing error. Measurements of the instantaneous frequency permit analysis of the delay times of secondary signals partially overlapping with earlier primary signals, down to the primary signal detection level.

Simultaneous measurements of the mean instantaneous frequency and the amount of instantaneous phase fluctuation over the first few seconds after the primary signal onset provided significant separation between the populations of shallow Eurasian earthquakes, Russian presumed nuclear explosions (including peaceful explosions), and Nevada Test Site presumed nuclear explosions, even at signal-to-noise ratios below 0 dB.

3. Technical Report No. 5: Study of Adaptive Beamforming Algorithms for Low Magnitude Seismic P-Wave Detection

A linear adaptive algorithm was developed for array beamforming purposes. The design goal for the algorithm was to minimize the squared filter output subject to the constraint which allows energy propagating from the array steering direction to pass without being distorted. The adaptive filter coefficients were designed as time-varying filters applied to each channel subject to the above constraint. The adaptation rate was inversely varied with filter output and total input channel power. Performance of the algorithm was studied by using recorded short-period array data from the Korean Seismic Research Station. To demonstrate adaptive beamforming, a high amplitude signal from Kamchatka, a medium amplitude signal from eastern Kazakh, and a number of low amplitude signals from central Eurasia were processed. Results of signal-to-noise ratio gain relative to a conventional beamformer among the events tested were consistent and were in the range of 4.5 to 6.5 dB in the wide passband. Much better signal-to-noise ratio improvement was obtained in a low frequency passband.

The directivity response pattern suggested that the adaptive filter maintained a response similar to that of conventional beamforming in the 60° beamwidth of the mainlobe and was better beyond the mainlobe. Also, simulation with signal added to scaled noise at various levels suggested that the processing gain and threshold reduction were consistent.

The adaptive algorithm was programmed in the real-time mode and can be implemented in a front-end detection system.

4. Technical Report No. 6: The Detection Association Processor

This report evaluates the feasibility of automatic location of events in a seismic network. The processor is called the Detection Association Processor (DAP). A DAP is a method to convert a list of station detection bulletins into an event list. It discards the false alarms and estimates the location, origin time, and depth of each seismic event. This method was developed for single site detection, array detection, and mixed network detection. Analysis has been done by the non-linear least square estimator, the weighted non-linear least square estimator, and the Geiger's method.

Results obtained from the above analyses by the observation of arrival time, azimuth, and ray parameter $dt/d\Delta$ are shown in Table II-1. The ratio of successes to failures shows significantly better results were obtained for the single-site DAP which locates by exhaustive search of a grid of location and tests predicted station arrival times against those observed. The other DAP method utilizes a Kalman filter to update locations by using the arrival time, direction and velocity information provided by an automatic detector. The association test based on location error measurements was too stringent as indicated by the 1σ, 2σ, and 3σ rejection tests shown in Table II-1. It is noted that about 80 to 90% of the association failures were caused by small events being croweded out of buffer space. This problem can be solved by parallel buffers associating several events at the same time

TABLE II-1

DETECTION ASSOCIATION PROCESSOR RESULTS

	Single-Site	Array	Mixed Network		
			1σ Rejection	2σ Rejection	3σ Rejection
Total No. of Events	128	100	100	102	102
Successes	40	30	12	26	29
Failures	17	17	35	24	21
Interfered Events*	29	21	21	22	22
Events Detected at Less Than 4 Stations	42	32	32	30	30

* Interfered events are failures of the automatic detector to properly time events. Large timing errors were caused by misidentification of the P phase due to interference with other event phases. Most of these large timing errors could easily be prevented by improving the logic of the simulated automatic detector used for this analysis.

and by dynamically changing the criteria for aging detections based on the rate of detection accessions by the DAP. These results were obtained by simulation of world-wide networks. Since the event bulletin is known, the evaluation of association and location estimation errors is made easy. These preliminary results suggest that automatic association is feasible, but more design work is needed to perfect the method. The implication of automatic detection and location is real-time event bulletin generation and editing of seismic events.

5. Technical Report No. 12: Empirical Relationships Between Seismic Noise and Magnitude Bias Applied to Estimating Network Detection Capability

An analysis of forty-six stations with known magnitude bias, noise amplitude, and tectonic structure shows that relationships exist between these three parameters. In order to use these relationships to assign bias and/or noise values to additional locations throughout the world, three models are used to define the relationships. These models are a line model, a tectonic-noise group model, and a tectonic model. The line model assumes a linear relationship between bias and noise. After examining all possible slopes of the line model it was found that a slope of one results in one of the more statistically significant normal groupings of the station noise values. Therefore, a slope of 1.00 is used to define various noise level groupings with zero bias. The tectonic-noise group model is an alternative interpretation which uses mean values of bias and noise for each combination of noise group and tectonic type. Finally, the tectonic model uses mean values of bias and noise for each tectonic classification.

Bias appears to be primarily affected by upper mantle structure characterizing the tectonic province associated with seismic stations. The noise level groupings appear to be more dependent on other factors such as crustal structure at the receiver region. Noise groups are consistent over large geographical areas, but these areas may encompass sections of more than one tectonic province.

Certain regions of the world have relatively stable short-period noise fields all year around. The continental locations of these regions on the continents appear to be primarily dependent on wedges of recent marine sediment and the distance these wedges extend from the coast.

By making use of the relationship between magnitude bias, noise, and tectonic structure to assign station parameters to various sites throughout the world, and by confining those locations to regions where noise is relatively independent of season, a simulated network of one hundred stations that are relatively insensitive to seasonal changes can be evaluated. The 50% detection threshold capability of this network for a 4.0 m_b event encompasses most of the world. Substitution of arrays for single-sites in lower latitude and Circum-Pacific locations results in a gain in detection capability of about 0.25 m_b for most of the world.

C. SIGNAL ESTIMATION TECHNIQUES

1. Technical Report No. 7: Extraction of Long-Period Bodywaves

This report presents the results of a study of detectors for long-period bodywave phases. It was motivated by the fact that there is a good separation between the earthquake and explosion populations by means of long-period bodywave magnitudes, and these phases therefore provide additional discriminatory power where they can be detected.

When a simple bandpass filter is used as the only processing scheme the 50% detection threshold, the short-period magnitude at which half of all events are detected by means of long-period bodywaves, is about m_b = 5.5 for P waves and about 5.1 for S waves, considerably higher than the corresponding threshold for surface waves of about m_b = 4.6.

Two conclusions can be drawn from this study. First, while the detectors studied here appear to be promising in terms of improvement in detection capability of long-period P waves, leakage of energy from phases which should be nulled by the detector probably leads to less than optimum performance. A model for the motion of P waves closer to the true particle motion should reduce this leakage and lower the detection threshold. Also, S wave particle motion should be investigated to explain the lack of positive results.

Second, there is evidence that part of the responsibility for the P detector's performance lies in apparent nulls in the radiation pattern peculiar to the data set used here. If this is the case, another data set should be used for any future evaluations. Some means may also be needed to correctly account for the effects of multiple radiation patterns on the detection capability of events from a given source region. Some consideration should be given to a joint measurement of long-period P wave and S wave bodywave magnitude which minimizes the effect of radiation patterns on detection and measurement of magnitude.

2. Technical Report No. 8: Extraction of Long-Period Surface Waves

Gains from a cascaded Wiener filter, three component adaptive filter, and prewhitened matched filter were measured for various orders of application to long-period surface waves buried in seismic noise. It was found that the gain of the cascaded Wiener filter followed by the three component adaptive filter was greater than the sum of their individual gains, and that this was the best order of application, but that following them with the matched filter reduced the overall gain over the range of input signal-to-noise ratio of interest. These results are due to the non-linear nature of the TCA and to the distortion inherent in its output.

A large number of earthquakes from the Kurile Islands as recorded at the Guam Seismic Research Observatory were processed using cascaded Wiener filter, TCA, and matched filter, in that order. The body-wave magnitude at which 50% of the events were detected by means of long-period surface waves was reduced from $m_b = 4.6$, the value when only a bandpass filter was used, to near $m_b = 3.8$. The precise threshold using cascading could not be determined accurately due to a lack of non-detected events at low magnitudes. Use of the matched filter added no detections to those achieved by the other two processors.

Surface wave magnitudes associated with these detections decreased linearly with m_b to about $m_b = 4.0$, where they decreased no further, due to bias from noise. Over their linear range they lay about 0.2 M_s units below the $M_s - m_b$ relation for bandpass filtered data, implying a signal degradation of that amount.

D. INTERACTIVE PROCESSING TASK

1. Technical Report No. 9: Extended Interactive Seismic Processing System

The primary intention of this report is to provide a comprehensive user manual for the Extended Interactive Seismic Processing System (ISPSE). ISPSE supports an interactive graphics environment on the PDP-15 computer located at the Seismic Data Analysis Center (SDAC) for the purpose of analyzing long- and short-period seismic waveforms. In addition to general signal analysis functions, ISPSE demonstrates the feasibility of utilizing interactive graphics for short-period event discrimination. This report discusses system features to ensure optimal utilization of ISPSE for seismic problem solving.

The main objective when extending the Interactive Seismic Processing System (ISPS) to the ISPSE is to develop software which would provide an operationally flexible, reliable, and attractive interactive environment for accomplishing standard seismic processing tasks. More specifically, the emphasis is to create a structure, which would free the geophysicist from the usual burdens of computer analysis (e.g., complex coding, batch compilation, and link editing) and permit him to concentrate on the solution of his seismic problems, without adopting the 'hard-wired' characteristics of many existing analysis packages.

With this objective in mind, ISPS was extended to support two new features, namely:

- A programmable mode of operation where standard seismic processing tasks may be defined (on-line, by the user) as a sequence of functions and sub-functions to be executed within the ISPSE environment. This minimizes decision making at task execution time and improves reproducibility of results.
- An interpretive high level Interactive Seismic Programming Language (ISPL) with which a user may define his own functions. These functions access, perform computations upon, and display data in tabular and graphic form for evaluation and analysis.

2. KSRS Data Transfer Task

This task involved the development of software to transfer KSRS data from the SDAC via the ARPANET to the Mass Store. This work involved the following major steps:

- In determining which Data Language transfer procedure would be operationally feasible for KSRS files in the Mass Store, the APPEND statement was found to be the most satisfactory. The KSRS port specifications were written to support this approach.
- The KSRS long-period, short-period, and coarse status file and port specifications were compiled and tested.

- The KSRS raw data field tape reformat program which generates long-period, short-period, and coarse status files on 9-track 1600 bpi tape that were compatible with corresponding KSRS port specifications was designed, implemented, and tested.
- The Data Language entry procedure by which an operator may realistically transfer KSRS data files to the Mass Store was specified.

To formally complete the KSRS Data Transfer Task, a demonstration was conducted for the Air Force during which KSRS data were transferred to and retrieved from Mass Store files managed by Computer Corporation of America's 203 Datacomputer.

E. SOURCE PARAMETER TASK

1. Technical Report No. 11: Determination of Seismic Source Parameters from Long-Period Surface Wave Data

The purpose of this study was to determine the seismic source parameters from long-period surface wave data and to investigate the influence of geological and near-source propagation effects on the frequency content of the surface wave signals.

The far-field long-period surface waves, both Rayleigh and Love, observed at the long-period seismic network have been studied for the presumed underground nuclear explosions at the United States Nevada Test Site (NTS) and Russian eastern Kazakh (EKZ), and for the peaceful nuclear explosions (PNE) in the north Caspian Sea region. A total of twenty-seven recent NTS, EKZ, and PNE events have been analyzed in terms of their surface wave dispersion characteristics, the Rayleigh wave attenuation along the travel path involved, their Rayleigh and Love wave spectra, and their seismic source parameter estimates.

The collective behavior of the Rayleigh and Love wave fundamental mode group velocities for each travel path involved has been obtained. For some travel paths, the theoretical surface wave dispersions for the normal continental or oceanic path can explain the observed group velocities quite well. However, the deviations of the observed group velocities from the theoretical group velocity curves are very noticeable in many cases. Therefore, the collection of the representative surface wave group velocity curves, which have been obtained here, along the travel paths from NTS, EKZ, and the north Caspian Sea region to ALPA, NORSAR, LASA, VLPE stations, SRO, and the SDCS stations will be helpful and can be used as guidelines for the future analysis of the surface waves of the seismic events in these three areas.

The Rayleigh wave attenuation coefficients (for periods from 10 to 50 seconds at 5 second increments) have been obtained for the continental and mixed paths from NTS to the observation stations, for those from EKZ to the observation stations, for oceanic paths from the NTS to stations in the Pacific Ocean, and for one path across the Atlantic Ocean (KON-ZLP). The agreement between the attenuation values obtained here and those calculated by other investigators is fairly good. In general, Tryggvason's attenuation curve has yielded quite reasonable attenuation corrections and is thought suitable for the average travel paths.

From the examination of the observed Rayleigh and Love wave amplitude spectra of these NTS, EKZ, and PNE events, it has been shown that the seismic sources of these explosions have various degrees of double-couple component in addition to the explosive source. The evidence of this double-couple component in these explosion events is indicated by the presence of Love wave motions observed at various recording stations and the azimuthal variations of the observed surface wave amplitude spectra. However, we have not observed any case where the Love wave amplitude is always less than the corresponding Rayleigh wave amplitude at a given station, as found by Lambert et al. (1972). The observed LQ/LR spectral ratios are found compatible with the average fundamental mode LQ/LR spectral ratios for the shallow earthquakes theoretically modeled by double-couple sources. This does not quite agree with the observations made by Lambert et al. (1972), that the LQ/LR spectral ratios for explosions are less than 1.0 and are much less than those for earthquakes. Although it has been found that there is a difference between earthquakes and explosions in the average frequency dependence of LQ/LR ratios, this difference is not thought to be sufficiently significant to be used as a discriminative feature between earthquakes and explosions, as implicitly suggested by Lambert et al. (1972).

The source parameter estimates of selected NTS, EKZ, and PNE events have been obtained by fitting the observed surface wave amplitude spectra with the theoretically calculated surface wave spectra of a combined source, which consists of the explosive source and the double-couple source. The double-couple source is used to model the possible tectonic strain release associated with the explosion. The depth estimates of these events indicate that most of them took place at very shallow depths (0.5 km). The very shallow depth estimates are thought to be very reasonable, since those events are presumed underground nuclear explosions. The dip and slip angle estimates of the NTS events do not quite agree with the assumption made by some authors (Toksöz, et al., 1965; Lambert, et al., 1972; Mitchell, 1975) that tectonic strain release associated with the NTS events can be modeled by a double-couple source with a vertical strike-slip type of mechanism (i.e., $\delta = 90^\circ$, $\lambda = 0^\circ$). The strike angle estimates for the selected NTS events are generally in the N-S direction, while those for the selected PNE events are close to the E-W direction. However, there is no general trend observed in the strike angle estimates for the EKZ events. No apparent correlation between the estimated F values (ratios of the radial over the double-couple moment) and the event m_b has been found for these events. The F values estimated for the NTS, EKZ, and PNE events are 1.0-1.75, 1.0-1.5, and 1.0-1.25, respectively. However, for the events with the same m_b, the estimated seismic moments of the tectonic strain releases associated with the selected NTS events are in general larger than those associated with the selected EKZ or PNE events.

From the source parameter estimates for these NTS, EKZ, and PNE events, the moment versus m_b plot has been found to be very promising for the purpose of discrimination between earthquakes and explosions. Several advantages of using the moment versus m_b plot over the conventional M_s versus m_b plot have been found, such as less scattering in both populations and wider separation, in terms of m_b, between the two populations. However, it must be mentioned here that the earthquakes are modeled by the double-couple source only instead of the combined source which is used to model the explosion events studied here. It is believed that the moment versus m_b plot will not be significantly altered by modeling the earthquakes with the combined source, since the double-couple source alone has been producing very satisfactory results for the earthquakes. Nevertheless, for a fair comparison, the earthquake events should be treated in the same way as the explosion events by using the combined source in the source parameter estimation for earthquakes.

SECTION III
SRO EVALUATION

A. CURRENT STATUS

During the past quarter, we have completed the following points in the SRO and ASRO evaluation:

- Routine processing of short-period and long-period signals and noise samples
- Plotting of Albuquerque, New Mexico (ANMO) long-period (LP) events was completed through 30 September 1976
- Compiled detection statistics from plots of ANMO events.

During this quarter we have also been engaged in the preparation of an experimental plan. Our objective is to reduce the level of effort of routine processing of events and to increase the scope of our analysis of events. Our preliminary results indicate that we can save two man months of effort by reducing the amount of noise data processed and the number of regions covered. This time could be used for the visual analysis of short-period data recorded on film to improve the evaluation of the SRO detector and for other analysis purposes. In this way, the evaluation of the SRO detector can be guaged against that of a visual analyst to supplement our present method of comparing its performance to an event list. Should we be able to obtain film chips or paper records at event arrival times given to us from an event list, we will be able to obtain more unbiased estimates of station detection capability based on the expected performance of a visual analyst. Presently for such comparative evaluations, we are restricted to data which are sent via the automatic detectors operating at the SRO sites. It is thus possible that bias in the estimated performance of stations is introduced by the conditionalities of the automatic SRO detectors performance. We are also considering the expansion of short-period parameters to be measured routinely in the analysis of SRO data. These could include arrival time and magnitude deviations, and other signal parameters such as short-period discriminant measurements. These tradeoffs between the amount of data processed and the amount of analysis performed are under consideration. The SRO and ASRO stations currently available for evaluation are listed in Table III-1.

B. FUTURE PLANS

We are currently engaged in SRO data processing and in finishing our experimental work plan.

TABLE III-1

SRO AND ASRO STATIONS CURRENTLY AVAILABLE FOR EVALUATION

	Station I. D.		Location of Installation		
	Number	Designator	Location	Lat. °N	Long. °E
SRO	30*	ANMO	Albuquerque, New Mexico	34.94	-106.46
	33	CHTO	Chiang Mai, Thailand	18.79	98.98
	35*	GUMO	Guam, Mariana Islands	13.59	144.87
	36*	MAIO	Mashhad, Iran	36.30	59.49
	38*	NWAO	Narrogin, Western Australia	-32.93	117.24
	41*	TATO	Taipei, Taiwan	24.98	121.49
	42*	SNZO	Wellington (South Karori) New Zealand	-41.31	174.70
ASRO	50	CTAO	Charters Towers, Australia	-20.09	146.25
	51	ZOBO	La Paz (Zongo), Bolivia	-16.27	-68.12
	52	KAAO	Kabul, Afghanistan	34.54	69.04
	53	MAJO	Matsushiro, Japan	36.54	138.21

* Evaluated in Technical Report No. 2 (see Section II)

SECTION IV

DETECTION, WAVEFORM EXTRACTION, AND MAGNITUDE ESTIMATION

A. CURRENT STATUS

Under the automatic signal detection task, modifications were made of the short-period Adaptive Beamformer (ABF) to the convergence rate for a prefilter of 0.5 to 1.5 Hz and another convergence rate for a prefilter of 0.5 to 3.0 Hz. A single convergence rate is desirable in order to enable the ABF to be used in an on-line mode with an automatic detector; also to be used for isolating and detecting later phases, such as pP. An algorithm was implemented to tune the array response to detect an event buried in the coda of a preceding event. This interfering event rejection method was developed by Wang (Journal of the Acoustical Society of America, Vol. 61, No. 5, 1977). Wang's method was tested by us on seismic data. As reported previously our initial results were negative. It now appears, however, that it is possible to provide effective elimination of interfering events by use of this method. Similar results in eliminating interfering events were also obtained by use of the ABF steered to the desired event.

Under the long-period waveform extraction task, the feasibility of a digital, time-variant resonance filter is under consideration. The purpose is to improve the efficiency of the Time Variant Wiener Filter (TVWF) for estimating dispersed surface wave signals. Also under consideration is the extraction of weak bodywaves by polarization filters. Past studies have indicated that although weaker signals can be detected, the variance, due to filter distortion and interactions with noise, is very large and the false alarm rate high. Procedures are being derived to utilize the Wiener or bandpass filter cascaded with the three component adaptive (TCA) filter to extract weak surface waves. Problems with false alarm rates and large signal amplitude variances are being examined, and an attempt is being made to more accurately estimate the detection capability obtained by use of polarization filters. Based on last year's results, shear wave detection did not appear to be a promising application of polarization filters. Particle motion plots of shear waves are being studied to possibly improve the application of polarization filters to the extraction of shear waves.

A tentative explanation for a phase shift of about 90° between components of the SV phase at epicentral distances of 32°, as used in last year's study of long-period bodywave detectors, was developed. It involves the existence of a converted P wave at the Moho, having a relatively large amplitude at this distance, and arriving at the surface about a quarter period after the direct SV wave.

Under the unbiased magnitude estimation task, the slope of the M_s-m_b relationship is apparently biased at low magnitudes due to noise in accordance with Ringdal's theory, (Maximum Likelihood Estimation of Seismic Event Magnitude from Network Data, Texas Instruments Technical Report No. 1, 1975). Methodologies are being examined to reduce this source of magnitude bias in measuring weak signals. The distribution of noise magnitudes is being studied both by time domain measurements and by Monte Carlo simulation. There is some evidence that the magnitude distribution is skewed positively. This is contrary to the assumption of Ringdal's network bias model. The validity and significance of the effect needs to be examined further.

B. FUTURE PLANS

Currently, under the ABF study, signal-buried-in-noise and mixed-signals simulations are continuously being investigated in various passbands. The amplitude shading techniques are being extended to complex-filter weights formulations with types of constraints. In the near future, the ABF will be applied to the problem of long-period surface wave extraction.

Under the long-period waveform extraction task, a long-period adaptive filter (ABF) will be designed for ILPA. The Time-Varying Wiener Filter (TVWF) will be run on the ABF output. A time domain version of the TVWF will be programmed. Examination of polarization filter data will be continued with the goal of improving the detection of bodywaves, especially shear waves. The resultant improvements will be tested on a data set selected to minimize bias due to radiation patterns and epicentral distance variations.

Noise and signal magnitudes for single site ALPA data will be measured for events between $m_b = 4.2$ and 4.8, where almost all events were detected on beams. Ringdal's bias correction method will be used to correct the single site magnitudes, which will then be compared to the 'true' beam magnitudes to test the bias correction procedure.

SECTION V
EVENT IDENTIFICATION STUDY

A. CURRENT STATUS

Under the event identification task, the type of event data and associated information needed, sources of the data, and algorithms for computing discriminants are being examined. The approach which will be followed is to rapidly reduce the data to essential event discriminant information, then perform a multivariate discriminant analysis of this information which results in event identification information. The first step in the process is to separate the data into events of shallow or unknown depth (e.g., less than 30 km) by hypocenter computation. The second step is to confirm later phases by analysis of pP, reducing the data to a set of apparent shallow depth events of unconfirmed depth of focus. The third step is to classify the event as a shallow earthquake or explosion type event based on short-period teleseismic spectrum, pulse characteristics (e.g., complexity), and cepstrum analysis. The fourth step is to classify the event based on long-period discriminants such as M_s, and the fifth and final step is to classify the event based on short-period regional discriminants such as Pg/Lg (ratio of compressional to shear wave energy).

Our current efforts have been directed toward two areas - a literature search and creation of a suite of test events. The purpose of the literature search was to determine the conclusions of past researchers as to which methods of event identification are most effective. The majority of the literature dealing with event identification describes the M_s-m_b discriminant. Areas covered are the theoretical basis for the method, areas where the method does not work (some NTS explosions and Tibetian earthquakes), and extension of the methods to those events for which either M_s or m_b cannot be measured. Other methods of event identification discussed in the literature are complexity, bodywave phase ratios, spectral ratios, phase and frequency measurements, and cepstrum. The integration of these into a more general discrimination method is being considered.

The suite of test events is intended to be used to test each event identification method. The first part of each test will be to check out the identification algorithm. The second part of the test will be to determine the relative value of each method. The event suite currently being created consists of all available short-period and long-period SRO and ILPA data for nuclear explosions and comparable-magnitude nearby earthquakes.

B. FUTURE PLANS

During the next quarter, we will continue our literature search and complete formation of the first test event suite. Our major effort will, however, be directed toward planning the flow of the overall event identification program and setting up the M_s-m_b module of this program.

In planning the overall program flow, we must consider which event parameters must be entered into the program, which parameters can be calculated by the program, and at what point each parameter should be entered or calculated. For example, in the past when measuring M_s we have used two program variants; one which required entry of a time gate and one which computed the time gate. We shall have to determine which variant to use in the event identification program and at what point in the program this time gate will be determined.

In setting up the M_s-m_b discriminant module, we will build on the existing M_s-computation program. Three points which must be considered are determining local m_b when short-period data are available, determining the above-described time gate for M_s computation, and possibly extending the method to those cases where either m_b or M_s cannot be measured but upper bounds from noise data can be determined.

Under the event identification task, programs required to generate the discriminants to be used will be written and tested using SRO data. The modification of our software (edit, remove trace mean, and rotate) which is used for SRO evaluation will be continued so that it can be used to process and compile discriminant measurements as the event data are collected. The discriminants will be subsequently used for event identification processing.

SECTION VI
SURFACE WAVE STUDY

A. CURRENT STATUS

Under the surface wave study task, the spectral fitting program was revised to automate iterations of the exhaustive search for minimum residual source mechanisms. The purpose is to reduce the number of computer turn arounds and CPU time required to obtain solutions. The possibility of applying the moment tensor method to the combined explosion and induced tectonic source mechanism was examined without any positive results. Possible future applications of the moment tensor method are presently deferred. An earthquake example was run on the combined source mechanism. The ratio of explosion to earthquake moment, $F = M_x/M_e$, obtained as a minimum residual solution was 0.25. This indicates the possibility of using this as a discriminant as values of F between 1.0 and 2.0 were obtained for all presumed explosion type sources examined last year.

The following is a summary of results obtained in speeding up the computation time of the exhaustive search method and preparing data for analysis:

- The possibility of making a table to save the calculations of theoretical spectrum was examined without positive results
- The spectral fitting program was revised by applying the binary search method to reduce the increments of parameters which are depth, F value, and strike angle. This revision cut the CPU time down to one-third of the previous method's calculation time

- Searching and selecting events (through 1976) for this year's analysis.

B. FUTURE PLANS

During the next quarter, emphasis will be placed on selecting events and preparing data for discrimination. It appears at the present time that the phase of optimizing the software is completed. Any further improvements in the efficiency of the computation will be through improving the efficiency of the algorithms by multivariate interpolation.

SECTION VII

SEISMIC DATA MANAGEMENT

A. CURRENT STATUS

Under the seismic data management task, the objectives and functions to be performed by the Mass Store Data Retrieval System (MSDRS) are being examined. The objective is to retrieve KSRS data from the Mass Store. The system will utilize existing data language software. The task involves the design and implementation of a KSRS Data Retrieval Command Interpreter (DRCI) which performs the following functions:

- On execution DRCI prompts the user to specify the parameters for retrieving data and where to put it
- The DRCI generates Data Language to reflect the parameters entered by the user and store it on a disk file for access by the data language software.

A course for TI personnel on the application of the Extended Interactive Seismic Processing System (ISPSE) to this year's discrimination task will be presented by the authors of last year's Technical Report No. 9 entitled, "The ISPSE". The course will be based on topics discussed in that report including an introduction and overview of ISPSE, the ISPSE Command Language, the Interactive Seismic Programming Language, the construction of standard seismic processing tasks via programmed procedures, and the use of ISPSE for discrimination. Each of these topics will be presented in a separate session with a variety of examples and hands-on experience at the system console. The objective of the course is to provide our scientists with a convenient mechanism for interactive analysis of large discriminant data bases.

Also, under the data management task, the programs TISROPRG and TISROSPE were combined into a single program. (TISROPRG is a program which combines the previously used SRO long-period edit, rotation, filter, and plot programs so that data may be prepared for analysis in one stage. TISROSPE is a program which edits SRO short-period data.) The resultant program, also now named TISROPRG, was tested and debugged. The combined SRO program was modified to use a new event header, compatible with the sub-set tape format and also applicable to all arrays and single sites. A program was written to read SRO edit and SRO data preparation (if three component - rotate from V, N, E to V, T, R; zero mean) tapes, and write tapes with new event headers. In addition, a combined edit program was written to handle all long-period arrays.

B. FUTURE PLANS

Under the data management task, desired data retrieval capabilities will be discussed with our project monitor. User and maintenance manuals will be examined to determine practical limits in designing the MSDRS. The documentation is expected to describe the UNIX operating system and the data language software. Also, software consolidations designed to improve the efficiency of large scale data processing will continue, as will continued development of the data preparation and data transfer programs.

C. PROBLEMS

The TS44 system was changed to allow a smaller maximum number of bytes per track when doing disk I/O. Our programming staff was not notified. This caused some of our disk I/O to cease functioning until we found out.

SECTION VIII
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